Advances in Computer Science and Information Technology (ACSIT)
p-ISSN: 2393-9907; e-ISSN: 2393-9915; Volume 2, Issue 14; October-December, 2015 pp. 14-17

http://www.krishisanskriti.org/Publication.html

4G Wireless Network Evolution- LTE to LTE-A

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Abstract—*The paper begins with a brief discussion on 3GPP Rel 8-LTE (Long Term Evolution) which uses techniques like MIMO, OFDMA (in downlink) and SC-FDMA (in uplink). We study the diversity and advanced methods like channel dependent scheduling and hybrid-ARQ, it uses to improve its capacity. We then study the application of reference symbols or pilot signal in LTE. Then we look at the specifications of IMT-Advanced for 4G systems and compare it with LTE & LTE-Advanced, where it is seen how LTE-A(3GPP Rel. 10)exceeds the requirements for 4G systems. The concepts of LTE-A such as, carrier aggregation for bandwidth improvement, Coordinated Multi Point operation (CoMP) and relaying are described.*

Keywords*: OFDMA, SC-FDMA, hybrid ARQ, carrier aggregation, CoMP, Relay nodes, reference signal.*

1. INTRODUCTION

4G technologies are simply IMT Advanced technology meaning they satisfy the requirements stated by ITU-R M.2134-2008 [2]. Some of the major requirements were like the network for 4G should be completely IP based. The data rates should be 1Gbps for stationary objects, and 100Mbps for high mobile objects. There should be seamless connection throughout the globe with soft and smooth handovers. LTE is nearly 4G as it satisfies the requirements partially.

ITU approved two 4G technologies in October 2010; they were LTE Advanced and Wi-MAX Rel. 2. Both the technologies not only satisfied the requirements but they surpassed them providing better than expected 4G services. 3rd Generation Partnership Project (3GPP) developed standards for 3G systems like UMTS and so on. They come up with different releases every year with up gradation over the previous release. They developed two standards LTE (Rel8) and LTE-A (Rel10). The major breakthrough was to use a frequency reuse factor of 1, which meant using the same frequencies everywhere. This improved the cell capacity greatly and better data rates were delivered to users. But this creates a lot of interference. To reduce this interference, we need some sort of coordination.

To understand this, let us assume in a classroom all students are talking at the same time, at same level, in same language, the end result would simply be no one understanding anything. But if there is some kind of coordination or scheduling that when one talks, others listen then we may have more quality information transmission. LTE, LTE-A uses similar techniques to control interference. In this paper we study about such techniques used in LTE & LTE-A.

2. LTE 3GPP REL. 8

3GPP release 8 came in 2009 by which time 3GPP knew their LTE technology had missed certain specifications to be called as 4G technology. Nevertheless in market it is still referred as 4G. Technically speaking it is almost 4G or 3.9G along with Wi-MAX. Some key features that were introduced in LTE were pure IP based network architecture, frequency reuse factor=1, 4x4MIMO, global roaming, short frame sizes (10ms) for less delay, flexible bandwidth ranging from 1.4 to 20 MHz, adaptable to various frequency bands(700/1500/1700/2100 MHz), support for paired and unpaired spectrum [1]. LTE offers a downlink speed of 300Mbps and uplink speed of 75Mbps. We now discuss some of the important techniques that enabled LTE to be such a huge success.

3. MIMO

MIMO is multiple antenna technology that uses multipath transmission in wireless communications. It stands for "multi-input, multi-output".

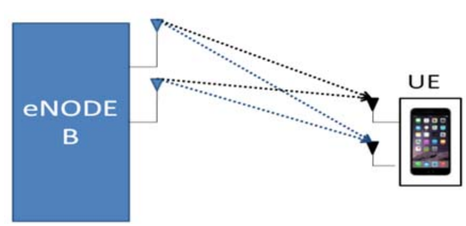

Fig. 1: 2X2 MIMO

With MIMO, we can achieve faster and better data rates with minimum errors as it combines the result at the receiver to minimize the difference. Both LTE and LTE Advanced use MIMO technology. LTE uses 4X4 MIMO for both downlink and uplink. LTE A uses 8X8 MIMO in downlink and 4X4 MIMO in uplink. Not all User equipments support MIMO; in fact there are only certain latest categories of User Equipments (UE) that supports it. Category5 UE supports 4X4MIMO. Category 6, 7, 8 supports LTE-A, with category 8 supporting all the latest features [3]. MIMO may have different transmission modes which it specifies to the User Equipment (UE) that indicates the type of MIMO it is using, number of antenna, number of antenna port, precoding type and type of reference signal. The transmission modes are specified to UE with the help of signaling.

One thing that should be noted in MIMO is that it is used only when the channel is good which means that the SINR is high. This specifically means that signal quality is good and interference is low. From this idea we can understand that MIMO can be used only near the Base Station where signal strength is high, and at the cell edges we should use some other technology like space-time diversity.

4. OFDMA

OFDMA is Orthogonal Frequency Division Multiple Access which is used in downlink for LTE and LTE-A technologies. In this we transmit the user data on subcarriers which are formed by splitting the large bandwidth. Each subcarrier is orthogonal to each other, which means when sampling one subcarrier, other subcarriers have zero amplitude.

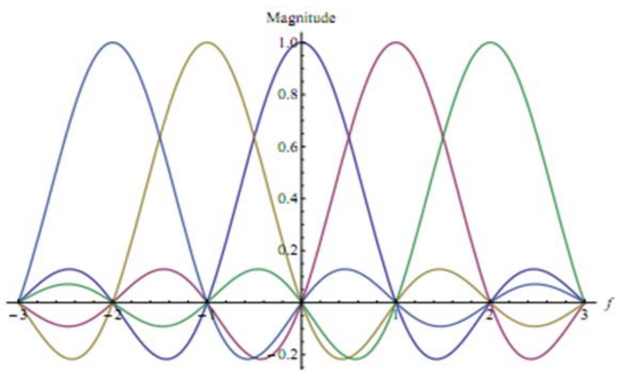

Fig. 2: OFDM signal

The advantage of OFDMA is in multipath transmission using MIMO, as there is less Inter Symbol Interference (ISI) due to longer symbol duration. But due to its multi carrier nature, it is subjected to have high Peak-to Amplitude Power Ratio (PAPR) as different carriers will contribute different power levels at any instant. This increases the complexity and cost of amplifiers needed. Thus it is only used at Base stations as they can only afford to have such large complex amplifiers. It is due to this reason that OFDMA is not used for uplink transmissions, except in Wi-MAX which uses OFDMA in both up/downlink.

5. SC-FDMA

SC-FDMA is used in uplink transmissions in all the latest wireless technologies. It is Single carrier FDMA in which each user gets a continuous spectrum for its uplink transmissions.

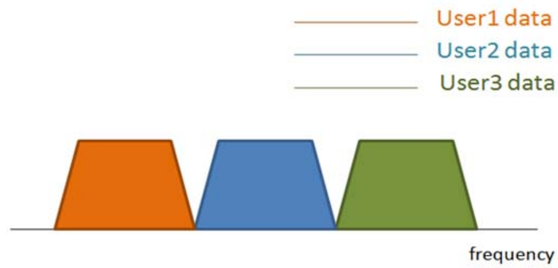

Fig. 3: SC-FDMA

Since it is only single carrier, the PAPR is not very high and normal amplifiers with less dynamic range are sufficient to cover the entire range of signal without clipping any part of the signal. SC-FDMA uses technique in its implementation similar to that in OFDMA. It uses FFT&IFFT which are simple mathematical tools and no major hardware is required except for CPUs. In fact, mathematically speaking SC-FDMA signal is simply Discrete Fourier Transform pre coded OFDMA.

6. CHANNEL DEPENDENT SCHEDULING

It is advanced technique used in wireless cellular networks. In this the Base station asks the user terminal at what sub carrier the user is expiring the best signal quality i.e. best SINR. The user terminal respond to it and the base station simply schedules the user terminal at that best frequency. It is implemented by focusing the transmission power in the user's best channel portion. This improves the throughput of the overall system. Also in LTE, the signal is randomly distributed in the entire channel using subcarriers. This prevents frequency selective fading.

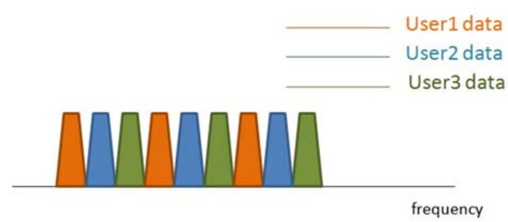

Fig. 4: Distributed allocation

Hybrid ARQ is the latest technology used in LTE which reduces delay. The word 'hybrid' is used because it is a combination of ARQ and puncturing [1]. With simply ARQ (Automatic Repeat reQuest), every time there is an error, there has to re transmission again which can increase the latency. In puncturing, large numbers of error correction code bits are used but only few are sent.

For example in ½ code with ¼ puncturing, there are 4bits for each 2-bit symbol and after ¼ puncturing the 4th bit is dropped. At the receiver side, the dropped bit is simply filled by a random bit and decoding is done. The hybrid ARQ is handled by the MAC layer.

7. REFERENCE SIGNALS

Reference signals, reference symbols or Pilot signals are the known symbols that are placed at a predetermined location also called the pilot location. Reference symbols are used to provide the information on how to implement MIMO (which port number, which antenna, and for what destination port) [3]. Reference symbols define the pilot pattern which can be used by the User Equipment (UE) to understand the type of pilot. Reference symbols transmit fixed and specific information; therefore it can be used for determining the phase and frequency errors if there is any alterations in the fixed known information.

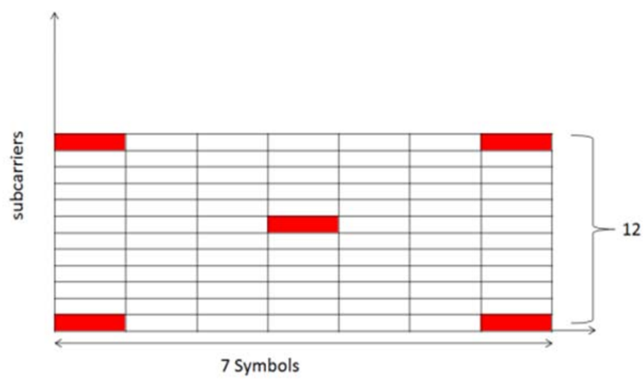

Fig. 5: Reference signals

8. LTE-ADVANCED 3GPP REL. 10

In October 2010, ITU approved LTE-A as 4G technology. When 3GPP was developing LTE-A, they wanted to cross the expectations.

Table 1: Specifications comparison

	DL spectral efficiency (bps/Hz)	UL spectral efficiency (bps/Hz)	DL peak data rate (Gbps)	UL peak data rate (Gbps)
IMT-A	30	14	1	0.275
LTE	15	3.75	0.326	0.086
LTE-A	30	15	3	1.5

The table clearly shows how LTE-A exceeded the IMT-A requirements for 4G technology [2]. LTE-A not only has features of LTE but also uses new methods to improve the capacity. We now discuss some practical techniques used in LTE-A these days to achieve such high capacity.

9. CARRIER AGGREGATION

Spectrum has two parts bands and bandwidth, and if bandwidth is improved the data rate can be increased. To improve the data rate, LTE-A can use a bandwidth up to 100MHz. But 100MHz bandwidth is not available even at high frequency bands of 2.4GHz. So in LTE-A, carrier aggregation or carrier summation is performed. In simple words, this means combining the multiple bands or component carrier. We can component carriers of following bands: 1.4, 3, 5, 10 or 20MHz.

We can have component carrier of equal or different bandwidth. With carrier aggregation we can combine some old unused spectrum with new available spectrum to have a much higher bandwidth. With this the transmission rate can be very high. This new technology should be backward compatible with the previous generation LTE. This is possible because when the UE is using LTE then it listens to one of the component carrier.

In practice, the Physical, MAC, RLC layers are all extended to handle the variable carrier components. There are bigger buffers used in RLC [4]. It may look like very simple but actually it is very difficult and complex to aggregate carriers. 3GPP in their LTE-A Rel. 10 specified that maximum five bands can be aggregated together as one [3], providing maximum bandwidth of 100MHz with each component carrier having bandwidth of 20MHz.

It should be noted that number of carrier components in downlink is always greater than or equal to the number of carrier components in uplink. This is because the base station is much powerful and can handle power issues better than UE. Carrier aggregation can be contiguous or non-contiguous.

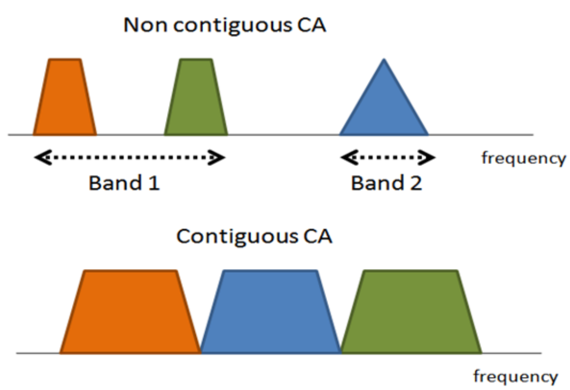

Fig. 6: Types of carrier aggregation

10. COORDINATED MULTI-POINT

In LTE-A, we have the frequency reuse factor equal to 1 which means that we are using the same frequencies all over. With this concept, we are fully utilizing the Bandwidth available but this will create trouble for the UEs at the edge of a cell as they will get interference from the other sides. The performance at the edges is improved with the technology called Coordinated Multi Point operation (CoMP). With CoMP the base stations can communicate with each other [5]. This is possible because although 4G is wireless but the eNodeBs are still connected with each other through wires. Now when Base Stations (BS) can talk, they can coordinate the transmission and reception at the cell edges. This forms the basis of CoMP.

Let us assume an example where one UE is at the cell edge and is receiving interference. Now the UE will inform the BS1 that it is getting interference from the neighboring cell BS2. Now the two BSs will communicate and coordinate their transmission by reserving the specific Resource Blocks (RB) for them, say BS1 has reserved RB with slot 2 and carrier group 4. So the BS2 now cannot transmit for that resource block. In this way collision is avoided and no two BS will transmit for same RB, at same time to the same UE, thus reducing the interference. It should be noted that RB are fixed only the cell edges not near the Base station. There are two types of CoMP: Joint Transmission & Reception where there are multiple transmissions and receptions in the same sub frame and Dynamic Point Selection where there is scheduling of transmission and reception.

Using CoMP, LTE-A has managed to reduce its cell size with concept of relaying. The macro cell now contains another smaller cell which uses the same radio resources and is almost identical to the bigger macro cell for the UE. This smaller cell is called the Relay node, while the macro cell is called Donor cell. These smaller relay nodes are low power base stations that are mainly used for performance enhancement in areas like hot-spots, malls, trains, cell edges. A modified version of air interface called ‘Un’ is used [6]. Both relay and donor cells may use same or different frequencies. One difference between Donor eNode B and relay node that separates them clearly is that relay node is blind to the outside world, whereas the donor node is responsible for mobility management.

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